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STORAGE AND TRANSPORTATIONAL DISEASES OF VEGETABLES DUE TO SUBOXIDATION

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GENERAL CONSIDERATIONS

The enormous shrinkage and deterioration in quality of fruits and vegetables under storage and transportation conditions has long been a subject of great concern to all those who have been connected directly with these phases of food handling. No estimate that will give an adequate idea of the waste that occurs annually in the handling of fruits and vegetables can be given. Some fragmentary reports are available which indicate the magnitude of this problem. The American Association of Refrigeration reported that $4,977,383.09 in claims was paid by 180 railroads in 1914 for such losses of perishable freight. Over one-half of this amount was for fruits and vegetables. Considering the great increase in the volume of perishable traffic now handled by the railroads in comparison with that handled in 1914, the present day losses of this kind are to be placed at a much higher figure. Fungous and bacterial diseases of plants play an important role in bringing about these losses. Scientific investigation has provided the necessary information, if applied, to reduce the losses of this type (8)[1]. in the case of most fruits and vegetables, a sound product from well cared for fields, if properly handled and stowed in the cars, can be delivered to market without serious loss from fungous and bacterial decays. Great progress is being made in eliminating waste of this sort.

There is another kind of deterioration, in which fungi and bacteria are not primarily concerned, that has largely been neglected. The manifestations of deterioration of the type considered in this bulletin can not be included under any one descriptive term, since the effects produced vary with the fruit or vegetable. This bulletin is concerned with the leaf specking, surface pitting, surface blemishing, and the internal discolorations which arise under the conditions of storage and transportation in tight cars. These diseases, which are of non-parasitic origin, are of greater economic importance than is commonly known, and the prevention of losses from this source means greater economy in the handling of fruits and vegetables.

Development of proper methods of handling perishables to eliminate these blemishing diseases, involves a consideration of the factors concerned in the life processes of plants under the peculiar conditions of cool, close storage, in order to determine the proper manipulation of temperature, aeration, and other factors which play the all-decisive part in the successful handling of perishable products in storage and transportation. The investigations reported in this bulletin demonstrate the imoprtance of such factors and the need for certain modifications in the present methods of handling vegetables in storage and transportation. This work was begun in 1919 in an attempt to determine the cause of a leaf speck disease of cabbage prevalent in storage and in transcontinental shipments. During the course of this

[1]Reference is made by number to "Bibliography" p. 37.

investigation diseases of a similar nature affecting other vegetables were included, as were some serious spot diseases of citrus fruits. This bulletin is limited to a discussion of the diseases affecting certain vegetables. A second report covering the fruit diseases will appear later.

BLACK LEAF SPECK OF CRUCIFERS

Introduction

A disease of cabbage characterized by the occurrence of innumerable, small, sunken, black specks on all parts of the leaves has been observed in Michigan for several years. It was found frequently in late winter on cabbage from storage houses or pits out of doors. In some cases, only the outer leaves were affected, while in others the spotting extended into, and often included, the heart leaves. The occasional occurrence of the specks on the youngest heart leaves practically eliminated the possibility of the disease being of parasitic origin. Microscopical examinations of sections and negative results from numerous attempts to isolate an organism from the lesions by the usual cultural methods early confirmed the belief that the disease was not caused by fungi or bacteria.

Observations made of shipments of cabbage arriving in Lansing from California in the spring of 1919 led to the discovery that a similar trouble was causing serious losses because of the close trimming of the heads necessary to make them salable (pl. 1, A and B). The disease in these shipments was not at first recognized as identical with that found on Michigan cabbage from storage because of the larger average size of the spots. The spotting of the leaves of the California cabbage was first thought to be due to the ring spot fungus, (*Mycosphaerella brassicicola*). Collections of the material were brought to the laboratory and attempts made to isolate the causal organism, but all efforts to demonstrate the association of a fungus with the disease gave negative results. Subsequent experimental work and further comparisons of the configuration of the lesions established the identity of the disease on California and Michigan cabbage. Shipments from Florida and Texas were later observed commonly to be affected with the same trouble.

While inspecting car lot shipments of fruits and vegetables from all parts of the country in the railroad yards of Detroit in 1919, several cars of cauliflower from California showing severe spotting of the leaves were examined. Photographs were made and collections brought back to the laboratory where it was found that the great majority of the spots were sterile and could easily be distinguished from a few larger lesions caused by the ring spot fungus. Attempts by two separate workers to isolate an organism from the small specks were unsuccessful. In appearance, the spots on cauliflower and broccoli were practically identical with those found on cabbage and left no question as to their identity (pl. 2, A and B).

In the fall of 1921, a planting of Chinese cabbage, (*Brassica pekinensis*), in the college horticultural gardens was found to be badly spotted with

the typical black specks characteristic of the cabbage and cauliflower trouble. Practically all of the heads in the planting developed innumerable black specks on all parts of the leaves following an early severe frost and a period of sixteen to eighteen hours when the temperature was near or below freezing. Microscopical examination of sections and tissue plantings on corn meal agar failed to reveal the presence of bacteria or fungi. No other observations have been made of the disease on this crop.

Brussells sprouts badly diseased with black leaf speck were collected on Cleveland markets in 1923. The specks occurred on all the leaves of the heads, and secondary rots were setting in.

Previous Observations

Only a few records are available of the occurrence of this disease, and all previous observations coming to the writer's attention have been made on cabbage. The disease has probably been confused with other leaf spots for the spotting of the leaves is disfiguring enough to be conspicuous and so destructive that badly affected heads could not escape observation. It is possible that Osmun and Anderson (19) may also have been dealing with this disease when they reported ring spot, (*Mycosphaerella brassicicola*) as causing considerable loss in March and April shipments of cauliflower from California. The two diseases are frequently found on the same head and the lesions on the leaves might easily be mistaken for one and the same disease. Observations made in April 1922 of California cauliflower on the Detroit market showed both diseases occurring on the same heads. Stewart (25) first reported the disease as generally prevalent on cabbage in the storage houses of New York and states that he has observed it since 1910. He also noted the disease in the field in the fall of 1910 and suggested that it might be of bacterial nature. Link and Gardner (16) record the presence of the disease on market cabbage from all regions. Link (14) found the variety Winningstadt affected in the field in California.

Name of the Disease

Stewart (25) first used the name black leaf speck in describing the disease on cabbage. Because of priority, and since this name also very well describes the usual appearance of the lesions observed on the leaves of other crucifers, it is proposed that it be used in designating the disease on all of crucifers affected with this trouble. Link and Gardner (16) used the name leaf speck to describe the disease as they found it on market cabbage. However, for the additional descriptive value, it seems advisable to use the longer name. No other descriptions have been found in the literature.

Importance

Black leaf speck has been found in many shipments of cabbage and cauliflower which have been en route for a week or longer. The disease may or may not be visible upon first inspection of the car. This is due to the fact that the spots on the leaves do not always develop until the heads are removed from the car and held in the ware-

house for several days. In other cases, the disease is first noticed on local lots of cabbage and cauliflower that are sent out to retailers. For these reasons, it is difficult to obtain first-hand data on the losses caused by this trouble to these crucifers in transit.

On the other hand, entire car loads of these vegetables may be severely affected with black leaf speck fully developed at the time of the initial examination of the car. In the spring of 1919, it was almost impossible to find on the market either cabbage or cauliflower from the West entirely free from the disease. The first lot of California cabbage arriving in Lansing required trimming away of more than half of the leaves to make the heads salable. Cauliflower was even more severely blemished. On March 29, 1919, a car of broccoli from Oregon was inspected in the railroad yards of Detroit. The crates were loaded seven tiers high and no spaces were left between the tiers or at the doorway for ventilation. Black leaf speck seriously disfigured every leaf in all the crates it was possible to examine. One of these crates photographed at the time of inspection is shown in plate 2, A. On the same day, crated cabbage was found generally affected with the disease in several of the wholesale houses. In 1920, the disease was common both on cabbage and cauliflower and has been observed each year since that time. In 1922, the disease was reported as especially severe on California cauliflower by railroad perishable freight inspectors and specimen heads were sent to the laboratory for confirmation of the diagnosis. The disease is not confined to western shipments but occurs as well on cruciferous crops from other sections.

In storage houses, black leaf speck sometimes greatly reduces the value of the crop and makes a large portion of it unsalable. The disease appears at the time when the market value of the crop is usually at the peak and for this reason storage losses may be unusually severe. Regardless of the perfect condition of the crop at time of harvest the disease may entirely ruin the highest grade heads. Wastage in the storage houses of New York state is exemplified by the following report by Stewart (25),—"In April 1911, a cabbage grower of North Tonawanda sent to the station some specimens of diseased cabbage leaves accompanied by the following letter: 'I send you some cabbage leaves of the Danish Baldhead variety, and should like to have you tell me what it is that affects them. This is only an ordinary sample, some being much worse. There was quite a large proportion of the crop affected. It was unsalable. It does not show until January when the cabbage gets white. We store in the barn where the temperature is kept just above the freezing point. We first noticed it a year ago on the crop of 1909.' The specimens sent were white leaves from the interior of a cabbage head." In the same article Stewart also reports the prevalence of the disease in Long Island storage houses in February 1915.

While no observations have been made of the disease in Michigan or Wisconsin storage houses, it seems likely that it is just as serious here as in New York, since cabbage in the retail stores has been found commonly affected with the disease after January.

Local growers largely store their crop in pits out of doors. The disease is often especially severe on cabbage handled in this way. In plate 3, A, is shown a head of cabbage and a smaller head developed

from an axillary bud badly blemished by black leaf speck. This cabbage was stored in a pit in the fall of 1919 and removed in early April 1920. Every head in this entire lot was badly diseased and worthless. The disease does not always affect all of the heads in this way although this condition is not uncommon. Heads so affected are not unsable as they have an unpalatable flavor when cooked. Secondary rots, mainly caused by *Sclerotinia* sp., occur generally on such heads. When only the outer leaves are affected, the removal of these produces a salable head, although it is not always of good quality.

In storage cellars, the disease affects winter cabbage in much the same way as in the pits out of doors. It is, however, usually less serious. If the heads are piled up in large heaps, as usually occurs where any considerable quantity is grown, the blemishing of the leaves reaches a maximum. One lot of cabbage taken from a large cellar storage in the winter of 1921 was observed to have fully 50 per cent of the heads affected seriously enough to require extensive trimming to make them marketable.

As a field disease, black leaf speck is probably of minor importance. Stewart (25) found it on cabbage in the field at Canandaigua, New York, in the fall of 1910 and reports that the inner as well as the outer leaves were affected. Link (15) reports the variety Winningstadt affected in the field in California. As has been stated, a planting of Chinese cabbage in the horticultural gardens of the Michigan State College was badly spotted with the disease in the fall of 1921. The disease developed after an unusually early and severe frost. Fully 50 per cent of the heads in this planting were ruined by the effect of the spots on the leaves. Cauliflower grown on low land was affected with this trouble in the late summer of 1924 following unusually low temperatures. Several observations have been made locally of the disease on cabbage in the fall. Unseasonable low temperatures following favorable growing conditions appear to be correlated with its appearance at this time.

Description of the Disease

The chief characteristic of the black leaf speck disease on crucifers is the occurrence on all parts of the leaves of innumerable, small, depressed, lead-gray to black specks. In severe cases, it is the usual thing for all of the leaves, including the small heart leaves, to show a general distribution of the black specks in the laminae and on the veins and midribs. In light cases of the disease, only the outer layers of leaves are affected. The spots very considerably in size, averaging less than 0.5 mm. in diameter. They occur singly or in clusters of myriad tiny dots scattered over the entire leaf surface. The most common picture presented by the disease on cabbage or cauliflower, in storage or transit, is a conspicuous disfigurement of the heads by the general occurrence of the black specks on the outer layers of leaves.

Observations of a considerable number of shipments of cabbage and cauliflower seem to indicate that the average size of the specks is larger when occurring on cabbage in transit, and that the lesions are smaller and more numerous on heads from commercial storage. For this reason, the disease may be more conspicuous in its effect upon the heads than when observed in storage. Plate 3, B, shows the appear-

ance of leaves collected from a shipment of California cabbage in March 1919. This lot of cabbage was almost uniformly affected in this way, the outer leaves showing the large coalescing spots, while the inner leaves were covered with the smaller and less conspicuous lesions. The large spots shown in the photograph may result from the coalescence of several or many small lesions, or they may simply be due to the simultaneous death of a large number of neighboring cells.

The shape and contour of the spots varies greatly. They may be circular, elliptical, oblong, or distinctly angular. The majority are circular or oblong with irregular margins as seen under low magnification with a hand lens. The spots, however, may be considerably elongated with the major axis either parallel or perpendicular to the veins of the leaf. All kinds of spots may occur on any portion of the leaf and the type of formation apparently bears no relation to their placement. Invariably the spots, large or small, are sunken below the level of the surrounding healthy tissue. They may be only slightly depressed, but the larger ones form crater-like areas in the tissues affected. The sunken character of the very small spots composing the colonies usually escapes notice unless magnified with a hand lens.

The leaves of cabbage taken in late winter from storage houses, cellars, or pits are often entirely covered with the black specks. In cabbage pitted out of doors, secondary growth often occurs which gives rise to small heads from the axillary buds. These are affected like the mother heads (pl. 3, A).

The disease severely disfigures the foliage of cauliflower in transit. California and Oregon shipments of cauliflower and broccoli often arrive on the central and eastern markets often so severely affected with black leaf speck that their value and salability is seriously impaired. A photograph of diseased cauliflower which is shown in plate 2, A and B, illustrates the condition in which many shipments from the far West arrive at their destination. Every crate in the car from which this sample was taken was similarly affected. Inspectors had been diagnosing this trouble as ring spot. The spots on cauliflower leaves are practically identical with those occurring on cabbage. The spots on the midribs appear to be more conspicuous and more sharply depressed than those of similar location and size on cabbage. A severe case of the disease on cauliflower often results in a yellowing and shedding of the leaves. When ring spot is present in any appreciable quantity, it is difficult to determine whether yellowing of the foliage is caused by the attack of the fungus or by black leaf speck and the conditions which cause it. This makes a complicated problem for the inspector who attempts to determine whether responsibility rests with the producer, the transportation company, or both. While the development of black leaf speck in shipments of cauliflower indicates unfavorable conditions within the car, the question arises as to whether or not these conditions are due to faulty methods of loading and stowing, or improper ventilation and refrigeration service. Either of these factors, or both, may determine the development of the disease while the crop is in transit. Delayed service in the movement of the cars will undoubtedly favor the occurrence of the disease. The flowers composing the head are rarely affected by the black leaf speck disease and apparently the quality is not greatly impaired.

Black leaf speck lesions may be visible from only one side of the leaf. The dorsal surface is most often the seat of the larger number of spots and, if the specks are small, they may be entirely invisible from the upper surface. Large spots can be seen from either side of the leaf. The very small specks are formed by the breaking down of comparatively few cells and the thickness of the leaf is a barrier to the free passage of light, so that until the leaves are removed from the head and examined separately the extent of the disease can not be determined. Stewart (25) also made this observation on specimens of cabbage from the storage houses of New York.

The specking is usually confined to the outer layers of leaves on heads affected in the field. In the only serious case observed in Michigan, all of the leaves of heads of Chinese cabbage were diseased; the effect of the disease is shown in plate 4. As a field trouble, the effect on the foliage is seldom severe enough to cause serious blemishing; and, whether blemished or not, the outer leaves are removed before marketing. The disease should, however, be distinguished from the effect produced by the attack of aphids.

Comparison With Other Leaf Spots

Other diseases with which black leaf speck is likely to be confused are: ring spot, (*Mycosphaerella brassicicola*); black leaf spot, (*Alternaria brassicae*); and McCulloch's cauliflower spot, (*Bacterium maculicolum*).

It is distinguished from the first two by the sunken character of the lesions and the general irregularity of their outline. Lesions produced by the ring spot and black leaf spot fungi are usually larger, more regular, and contain the fruiting bodies of the causal organisms. Concentric rings of spores are visible on black leaf spot lesions, and these aid in identifying the disease. In neither of these fungous diseases are lesions formed so freely on the midribs and veins of the leaves as is the case with black leaf speck.

Infection by *Bacterium maculicolum* takes place through the stomata and this is one means of distinguishing this disease. A stoma will always be found dotting the center of the lesion while the bacteria may easily be demonstrated by microscopic examination.

Stigmonose caused by the attack of aphids on cabbage and cauliflower in the field causes small black spots somewhat similar to those produced by black leaf speck. However, instead of being sunken, these spots are usually slightly elevated above the surrounding tissue. The absence of fungi and bacteria in the black leaf speck lesions makes microscopic examination a valuable means of identification.

Experimental Work

That black leaf speck was not caused by bacteria or fungi was early proven by repeated failures to isolate or demonstrate microscopically any organism in connection with the disease. Occasionally, hyphae are found ramifying through the dead tissues and, in severe cases of the disease, bacteria may cause secondary rotting; but, ordinarily, tissue cultures remain sterile. Further evidence that the disease was non-parasitic in its origin was shown by the failure of the lesions

upon the leaves to increase in size or extent when held under conditions that favor the development of parasitic troubles.

The occurrence of black leaf speck in shipments confined for a week or longer in refrigerator cars where ventilation is restricted, in storage pits where air renewal is largely prevented, and in storage houses and cellars where cabbage is piled in deep piles or stored in large bins suggested the probability that the disease might be similar in origin to black heart of potato as described by Stewart and Mix (*27*). The disease had been noted by Dr. G. H. Coons, for several years previous to this investigation, upon cabbage stored locally in out-of-door pits. The writer had found it commonly in transcontinental shipments of cabbage from California. The disease was found abundantly on both cabbage and cauliflower on the local markets, often in destructive form. For a while, black leaf speck was confused with ring spot, which also is found frequently on these vegetables from California and Oregon. However, critical examination and negative results from attempts to isolate *Mycosphaerella brassicicola* from the lesions led to the conclusion that the disease as it occurred locally on cabbage in pits and cellars was probably identical with the trouble prevalent on the California and Oregon cabbage and cauliflower.

Preliminary experiments were begun to determine, if possible, the general conditions which might produce the disease. Since it originated under conditions similar to those that produce blackheart of potato, the first experiments were designed to imitate these conditions. In all cases, clean, sound heads of cabbage were selected for the experiments. In case of any question as to their previous history, they were held at room temperature for at least three days. All wilted, discolored, or mutilated leaves were first removed so that the leaves were perfectly sound and free from blemishes. The effect of various storage conditions was determined by sealing seven lots of heads in large glass jars with ground glass tops and subjecting them to various conditions of temperature and aeration. In the early experiments, in order to shorten the period of storage, a portion of the oxygen was exhausted from the storage chamber by the use of pyrogallic acid and sodium hydrate solution. Not enough of the chemicals was used to exhaust all of the oxygen, tests showed about 5 to 6 per cent of oxygen remained in the jars. Later, this procedure was discontinued. In jars 1 and 2, no chemicals were used. These jars were filled with the heads and stored at the temperatures indicated in table 1. A portion of the oxygen was exhausted from jars 3 and 4 by chemicals, an average of 6 per cent remained after all absorption had ceased. Lots 5 and 6 were stored in carbon dioxide gas obtained from a Kipp generator by means of hydrochloric acid and lump marble. Lot 7 was aerated constantly by blowing a stream of air through the storage jar. All were stored at the temperatures given in the table. The temperatures maintained were approximately as given in the table, varying 1° to 2° daily.

In the entire series stored at 30° C., complete breakdown of all of the heads occurred. The leaves were soft, water-soaked, and leathery, and fermentation had taken place, which gave rise to a strong krauty odor in the jars. In lots 2 and 4, stored at 10° C., sunken water-soaked lesions appeared upon the leaves within 10 minutes to ½ hour after the heads were removed from the jars. After three days at room

temperature these sunken spots darkened and became typically colored. These spots were, however, neither so numerous nor so typical in shape or size as the small lesions found naturally on cabbage and cauliflower. Lots 5 and 6 stored in carbon dioxide remained normal in appearance but developed a slight reddening of the heart leaves in those heads held at the higher temperature. In the heads of lot 2, held for thirteen days at 10° C., this condition was very pronounced. This phase of the breakdown problem is discussed on page 19 of this bulletin in connection with a similar trouble affecting head lettuce. In lot 7, where fresh air was constantly blown through the storage jar, no specking or any trace of redheart developed in three days after removal from the jar. The outer leaves of these heads were slightly moldy and beginning to soften from the effects of the fungous attack (*Mucor* sp.).

Table 1.—Effect of various storage conditions in producing black leaf speck of cabbage.

Lot No.	Storage Condition	Temperature	Duration Storage	Results
1	Air-tight glass jar	30° C.	7 days	Heads all soft. Severe breakdown.
2	Air-tight glass jar	10° C.	13 days	Heads normal in appearance when jar first opened. Developed redheart condition in 1 hour and black leaf speck in 3 days.
3	Oxygen partly exhausted from storage jar with pyro and NaOH	30° C.	6 days	Heads all soft, watery. Anaerobic rots present.
4	Oxygen partly exhausted from storage jar with pyro and NaOH	10° C.	7 days	Heads normal in appearance when first exposed to air. Sunken lesions developed in 1 hour. Blackened in 3 days.
5	Air in storage jar replaced with CO_2	30° C.	5 days	Strong krauty odor in jar when opened. Heads developed slight redheart in 12 hours.
6	Air in storage jar replaced with CO_2	10° C.	7 days	All heads normal in appearance. No change in 5 days at room temperature.
7	Fresh air blown through storage chamber constantly	30° C.	6 days	Outer leaves moldy and softening. No specking developed in 5 days.

In a general way, these preliminary tests in which typical breakdown was produced experimentally indicated that breakdown occurred under conditions of poor aeration. Black leaf speck developed on the heads stored in jars with the oxygen partially exhausted and also where the percentage of atmospheric oxygen in the storage air was not reduced previous to the beginning of the storage period. That the factor causing breakdown was not the accumulation of carbon dioxide in the jars was indicated by the behavior of the heads stored at two different

temperatures in pure atmospheres of this gas. These heads appeared perfectly normal upon exposure to the air and developed no specking in three days. The necessity for holding the heads for observation for several days after removal from storage was demonstrated by the delayed and gradual development of the lesions of black leaf speck.

It seemed desirable to determine approximately the rate of diminution of oxygen within the storage chambers. Two large glass jars were filled to about one-half capacity with small clean heads of cabbage, and a third jar to two-fifths capacity. The jars were sealed and connected with rubber tubing. A bellows apparatus was attached so that the air could be thoroughly stirred before sampling. Jar No. 3 had almost double the capacity of Nos. 1 and 2. Analyses of the oxygen content of each jar were made at intervals by means of a Ganong apparatus (10). The gas readings were corrected by the usual formula. The jars were opened after five, eight, and ten days. The results are given in table 2.

Table 2.—Effect of length of storage period and air composition upon the production of black leaf speck: tests at room temperature.

Lot	Storage Condition	Duration of storage	Air Composition		Results
			Hours in storage	%Oxygen	
1	Sealed glass jar ½ filled	5 days	24 hours 72 hours	2.5 2.0	Breakdown as sunken lesions 1 hour after opening. Outer leaves developed typical black specks.
2	Sealed glass jar ½ filled	8 days	24 hours 72 hours 96 hours 120 hours	2.0 1.5 1.0 0.5	Krauty odor in jar when opened. Large sunken lesions formed on outer leaves 2 hours after opening. Blackened.
3	Sealed glass jar ⅔ filled	10 days	120 hours 168 hours 192 hours	2.5 1.0 1.0	Breakdown as very typical black specks in parenchyma and on veins. Developed gradually from sunken colorless lesions.

Breakdown occurred after five days, during which time the oxygen content of the air in the jars was reduced to a low percentage. Jar No. 3 was not opened until ten days after the beginning of the experiment. Due to the larger storage capacity and the relatively smaller amount of space occupied by the cabbage, the oxygen supply was greater and consequently was not depleted so quickly as in jars 1 and 2. Examination of the table shows that the sharp decline of oxygen in the jars occurred during the first twenty-four hours of storage. In jar No. 1, the reading after twenty-four hours of storage showed only 2.5 per cent residual oxygen, while in jar 2, for the same period, the amount was 2 per cent. Following this marked decrease during the first twenty-four hours, the decline thereafter was very slight, only 0.5 per cent in each of the first two jars for the next forty-eight hours. The last reading for jar No. 2 was made after one hundred and twenty hours of storage and showed 0.5 per cent oxygen yet remaining. In

jar No. 3 with a larger capacity, the initial reduction was almost the same for the first twenty-four hours but after eight days still showed 1.0 per cent oxygen present.

The results of this experiment indicate that respiration is very active in cabbage stored at a temperature of 18° to 20° C., and that if the oxygen supply is not renewed, at this temperature it quickly is reduced to a very low point. The condition of oxygen hunger was probably reached during the first twenty-four hours of storage in each of the three jars. The slow decrease in the residual oxygen after the first twenty-four hours is probably due to the depressing effect upon respiration of the accumulated carbon dioxide. The chemical changes that occur during respiration may be greatly inhibited by the presence of a large amount of carbon dioxide in the air. Brooks, Cooley and Fisher (6) have shown that apples stored in one to six per cent carbon dioxide are thereafter immune from scald and attribute this to an inhibition of the life activities of the apple. The natural accumulation of this gas in the closed storage chambers probably results in a retardation of the rate of the gaseous exchange and may prolong the tolerance of the cells to the condition of oxygen hunger. However, after three days at this temperature, the oxygen content had only been reduced 10 per cent below that reached after twenty-four hours of storage, and the disease developed on the heads following removal from the jar. Therefore, it seems probable that the base level of existence of these cells in a diminishing oxygen supply, even when the accumulation of carbon dioxide retards oxidation, may be reached within a relatively short time after storage at these temperatures if the oxygen content is not increased. The conditions of temperature and aeration of this experment are often simulated in the bulk shipments of cabbage in refrigerator cars. Respiration increases the temperature and failure to ventilate promptly or carelessness in following ventilation instructions may result in the depletion of the oxygen content of the car below the minimum required for the continued existence of certain groups of cells. Under refrigeration, the temperature inside the car may reach the level of 8° to 10° C. in the upper tiers of the load even when cabbage is shipped in crates. Very little air renewal is possible when the ventilators are closed, for refrigerator cars are practically air tight, especially when new. Similar conditions must also occur in pits in which cabbage is stored, and aeration is probably largely prevented by the practice of piling in large heaps in the storage houses or cellars.

In the preceding experiment, the most typical lesions of black leaf speck developed on the heads stored in jars in which the volume of air was greater in proportion to the space occupied by the cabbage than in the other two jars. The length of storage was ten days in comparison to five and eight days respectively for jars 1 and 2.

As a check on these first experiments and also to increase the range of conditions of temperature, length of storage, aeration, and other conditions, the next experiment was designed to test a wide range of these various factors. Three large aluminum containers (25 qt. pressure cookers) with air-tight covers were filled about half-full of small heads of cabbage. These three jars were stored at temperatures of 8° to 10°, 18° to 20°, and 30° C. Series No. 4 was placed in a similar container and connected with a pump to force fresh air through the

jar constantly and held at 20° C. A large desiccator was used for the next lot; and, in the bottom of this, was first placed enough sodium hydroxide solution to absorb the carbon dioxide produced. Lot No. 7 was stored in a large glass jar in which the air was displaced by carbon dioxide obtained from a Kipp generator. The last lot was placed in an open glass jar. Series 4 and 8 were all stored at the same temperature, 18° to 20° C. The results of these tests are given in table 3.

Table 3.—Influence of various storage conditions upon the production of black leaf speck of cabbage.

Lot	Storage Condition	Temperature	Duration Storage	Results
1	In air-tight 25-liter aluminum container	30° C.	5 days	Complete breakdown of all heads. All soft and attacked by anaerobic bacteria.
2	In 25-liter air-tight aluminum container	10° to 12° C.	12 days	All heads developed a severe case of black leaf speck after 2 days at room temperature. All outer leaves severely blemished.
3	In 25-liter air-tight aluminum container	20° C.	6 days	Typical black leaf speck lesions developed in 5 days at room temperature. Numerous, minute, sunken, colorless lesions visible when jars first opened.
4	In air-tight glass jar with fresh air blown through constantly	20° C.	6 days	Normal. Outer leaves slightly moldy. No specking developed in 5 days.
5	Stored in large glass jar over Pyro and NaOH	20° C.	4 days	Breakdown visible after 2 days as sunken spots in parenchyma. When opened after 4 days, spots numerous, large, not typical.
6	Stored in large desiccator over NaOH	20° C.	6 days	Typical black leaf speck lesions completely developed after 5 days at room temperature. In parenchyma and on the veins.
7	In large air-tight jar filled CO_2	20° C.	7 days	Normal. No change in 5 days. Strong pungent odor in jar when opened.
8	Stored in large, open glass jar	20° C.	10 days	Normal. No change in 5 days.

As in the previous experiments, complete breakdown of the heads occurred at the temperature of 30° C. The leaves were soft and watery and a strong krauty odor developed. At a temperature of 20° C., six day's storage was sufficient to produce typical lesions of black leaf speck. The numerous small, sunken, and colorless specks were visible when the heads were taken from the jar, but the characteristic dark brown to black color developed gradually during a period of five days. During this time, the heads were held in the ice box at a temperature

of 10° C. but were frequently removed for observation. This somewhat delayed the appearance of the typical color of the lesions but was found desirable on account of the drying out of the leaves when exposed to the dry air of the laboratory. When removed from jar No. 2 after a storage of twelve days at a temperature of 10° to 12° C., the heads of cabbage were apparently normal in every way. There was no unusual odor in the jar and the leaves of the heads were still quite green and bright. Moisture had collected slightly on the sides of the storage jar. These heads were left on a table in the laboratory and covered with moist absorbent toweling. Within twenty-four hours the outer leaves were showing numerous black specks, and two days after removal from storage they were badly blemished by innumerable, small, sunken black lesions that reproduced in every detail the normal appearance of the disease as found both in transit and in storage. Plate 5, (A and B), shows the general condition of all the heads in this series. The spots were located on the veins and in the parenchyma and were visible from both sides of the leaf. The lesions affected several layers of leaves and the development of the specks continued progressively inward on the leaves for several days. Very typical lesions were also produced on the heads stored over sodium hydroxide for six days. These appeared slowly, requiring five days for complete development at ice box temperature (10° C.).

By the reaction of the heads stored in carbon dioxide, it was again demonstrated that this product of metabolism is not the cause of black leaf speck. The heads stored in the gas were normal in appearance when taken from the storage jar and developed no signs of the disease. Lots 4 and 8 were subjected to a continuous change of air and were sound except for the development of mold on the outer leaves. No lesions of black leaf speck appeared on any of the heads of these two lots.

Effect of Air Movement

In the preceding experiments, it was shown that cabbage reacts somewhat similarly to apples when stored under conditions which are not favorable for ventilation and change of air. When the heads are stored where there is no renewal of the air, breakdown occurs on the leaves in the form of small black specks. It was also shown that the accumulation of carbon dioxide which occurs under such conditions is not the cause of black leaf speck. In discussing experiments on apple scald, Brooks, Cooley, and Fisher (6) state that this disease can be prevented by stirring the air of the storage house and that the composition of the air is not important, and they conclude that—"Stirring of the storage air has been found more important than its renewal in the prevention of apple scald." They believe that scald—"Is due to the accumulation of esters or similar products in the tissues of the fruit and in the surrounding air. The vapors of these substances can be carried away by air currents or absorbed by fats and oils." Since black leaf speck of cabbage occurs under storage and transportation conditions similar to those that produce scald of apples, some of the experiments used by the above investigators were tested in these investigations. Provision was made for agitating without effecting renewal of the air of the chambers in which the cabbage was stored.

A special air-tight box was constructed which housed a motor-driven fan. The outlet from this was connected by means of glass and rubber tubing to a large glass storage chamber through which the air was forced around the heads of cabbage and then led back again through rubber tubing to the fan box. The set up of the apparatus used in this experiment is shown in plate 6, B. A similar lot of heads was placed in a large storage jar connected to a suction pump and fresh air drawn constantly through it. The temperature was approximately 20° C. throughout the duration of the experiment. The duration of the exposure of these two lots was six and ten days respectively. The results of this experiment are summarized in table 4.

Table 4.—Effect of air movement upon the production of black leaf speck of stored cabbage: tests at room temperature.

Lot No.	Storage Condition	Duration	Results
1	Fresh air constantly drawn through storage chamber by suction pump	10 days	Heads all sound 5 days after removal from storage. Slight development of mold on surface leaves.
2	Air in continuous circulation by means of motor-driven fan, but not renewed	6 days	All heads with typical breakdown. Specks very small, located on veins and in parenchyma. Several layers of leaves affected.

The outer layers of leaves on all the heads of cabbage from lot No. 2 developed typical lesions of black leaf speck. The specking was quite general, affecting the veins as well as the parenchyma tissue between the veins. Practically all of these specks were very small and non-coalescent. In mild cases of breakdown such as represented here, the specks that develop are usually very small, numerous, and distinct; while, in severe cases, the lesions are more likely to be larger and coalescent. The heads bathed for ten days with a constant stream of fresh air did not develop any lesions of black leaf speck. The outer leaves that came in contact with the walls of the storage chamber were slightly moldy from the attack of a species of *Mucor*. The humidity in each of these chambers was high at all times and moisture was deposited as small drops on the walls of the jars. This favored the development of fungi which sometimes attacked the outer leaves.

There was no indication from the results of this experiment that air movement would prevent breakdown unless renewal was accomplished as well. However, further tests were made in order to fully establish this point. Variable conditions of temperature and air composition were provided. In lot No. 1, the heads were stored under conditions similar to those of the preceding experiment, the air of the storage chamber being constantly agitated but not renewed. Lots 2 and 3 were stored in large glass jars and the air displaced with nitrogen. These jars were stored at temperatures of 10° C. and 18° to 20° C. Number 4 was connected to a suction pump and the air in the jar constantly renewed. Lot No. 5, consisting of twenty-five or more small heads, was stored in a large, low temperature incubator equipped

with a motor-driven fan. The temperature was kept down to approximately 10° C. by means of ice in a chamber above the heads. When closed and all crevices sealed with modeling clay, the chamber was practically air tight. The heads could be observed through a glass door and temperature readings made from a projecting thermometer. The results of these tests are summarized in table 5.

Table 5.—Effect of composition and movement of the storage air upon development of black leaf speck in cabbage. Observations continued three days after removal from storage chambers.

Lot	Storage Condition	Temperature	Duration of Storage	Results
1	Air constantly circulated but not renewed	20° to 22° C.	3 days	Breakdown on some heads, mostly as minute specks at margins of the leaves.
2	Storage chamber filled with nitrogen	20° to 22° C.	2 days	Breakdown very severe. Outer leaves soft and heart leaves became red in color on exposure to air.
3	Storage chamber filled with nitrogen	10° C.	7 days	Breakdown severe. Outer leaves beginning to soften. Heart leaves of all heads reddened upon exposure to air.
4	Fresh air drawn through storage chamber constantly	22° to 25° C.	3 days	All heads sound. No change in 3 days.
5	Air constantly circulated by motor-driven fan but not renewed	10° C.	11 days	Mild breakdown on majority of heads. Typical black specks on outer leaves. Intumesences on cut stems.

In lots 1 and 5 stored at temperatures of 20° and 10° C. respectively, black leaf speck developed in a typical way after removal of the heads from storage. At the higher temperature, an exposure of only three days with the air in constant circulation inside the storage jar was sufficient to cause breakdown. In the preceding experiment on air movement, the storage period with unrenewed circulating air had been six days. Here with the time shortened to three days the disease developed on the margins of the outer leaves, not so abundantly as in the previous test with longer exposure, but characteristically, with the small specks typical of the mild form of breakdown. At the temperature of 10° C., the heads were exposed for eleven days. No evidence of breakdown could be observed on the leaves before the heads were removed from the incubator. However, the black specks appeared on some of the heads within 24 to 48 hours after removing them to the outer air and in addition small intumesences developed on the cut stems. The severity of the disease was much less developed than in an earlier experiment where the heads were stored for twelve days at approximately this same temperature in still air. However, the volume of air was greater in proportion to the volume of cabbage

in this test than the former and it is also almost impossible to prevent a slight entrance of fresh air into the apparatus used.

The cabbage in both nitrogen-filled jars was severely affected with breakdown. The outer leaves of the heads were soft and watery, becoming leathery on drying, and the heart leaves developed the red color. There was a pungent mustard taste in the leaves of these heads. In lot No. 4 exposed to a continuous stream of fresh air forced through the storage jar, the heads developed no breakdown in the usual observation period. The results of these tests seem to demonstrate conclusively that air movement, without renewal, is not effective in preventing the development of black leaf speck, and that in this respect this disease differs from apple scald.

Effect of Accumulated Storage Gases Other Than Carbon Dioxide

Although the experiments with air movement had given no indication that black leaf speck was caused by toxic volatile compounds of a similar nature to those causing apple scald, this possibility was further tested by collecting the gases given off by heads of cabbage in storage and exposing sound heads to them. Small, sound heads of cabbage were sealed in a large glass jar, the air displaced with nitrogen, and the jar held at room temperature for three days. A similar lot of heads was then placed in a second jar and the accumulated gases drawn over from jar No. 1 by means of a suction pump. The gases were passed through a tower containing potassium hydroxide to remove the carbon dioxide. A third lot of heads was stored in a glass jar and fresh air drawn over them through a suction pump. The heads were removed from jar No. 2 after being exposed to the gases for 24 hours. The results are shown in table 6.

Table 6.—Effect of volatile compounds other than CO_2 given off by cabbage in storage upon the development of black leaf speck: tests at room temperature.

Lot	Storage Conditions	Exposure	Results
1	Nitrogen gas for 3 days	0	Breakdown on all heads as sunken lesions on inner leaves. Outer leaves softening.
2	Sound heads in large glass jar	Gases from Jar 1 drawn through KOH to Jar 2. Left 24 hours	Heads removed after 24 hours and held at room temperature for 3 days. All sound.
3	Subjected to continuous stream of fresh air	2 days	All sound except for slight mold on one head at bottom of jar. No specking in 5 days.

The heads stored in nitrogen for three days were severely affected with breakdown. The outer leaves were softening and conspicuous, large, sunken spots were present. No specks or breakdown in any form appeared on the heads exposed to the gases from the original heads or on the heads bathed by a constant stream of fresh air during the period of storage.

The above experiment was repeated under similar conditions ex-

cept that the heads of cabbage were merely stored in a tight jar and left for three days. A second jar was then filled with fresh, sound heads of the same kind of cabbage and a partial vacuum created in the storage jar by attaching a vacuum pump and exhausting as much of the air as possible. This jar was then connected to jar No. 1 by means of very heavy rubber tubing and the stop-cocks closing each jar were then opened. In this way the gases from jar No. 1 were drawn into jar No. 2 until the pressure was equalized. The heads in jar No. 2 were then left for twenty-four hours at room temperature (20° C.). The results are shown in table 7.

Table 7.—Effect of gases given off by cabbage in storage upon the development of black leaf speck.

Lot	Storage Period	Exposure Period	Results
1	3 days	3 days	Breakdown as typical black specks developed on the leaves after exposing the heads to the air.
2	0	24 hours	Heads all sound after holding for 7 days exposed to air at room temperature.

The results of this experiment are similar to those of the preceding one and tend to show that toxic compounds of a volatile nature are not responsible for black leaf speck.

Effect of Low Temperature

In some of the preceding experiments, black leaf speck was produced by storing heads of cabbage at comparatively low temperatures. The disease was reproduced most typically at temperatures below which the ordinary parasitic troubles fail to develop actively. The disease as it occurs naturally in storage houses and storage pits, as well as in refrigerator cars, develops at temperatures from about 0° to 10° C. These extremes, however, do not represent the entire range of temperatures to which cabbage and the other crucifers are subjected in storage and transportation but are within the average range. Black leaf speck has been reported as causing serious losses in New York storage houses where the temperature was maintained near 0° C. (25). Its occurrence has also been noted in the fall in the field by Stewart (25). Reference has been made (page 5) to observations by the writer on the occurence of this disease following early, heavy frosts, both on cabbage and chinese cabbage. Link (15) reports the variety Winningstadt affected in the field in California but makes no reference to temperature. However, in the same article, he refers to freezing injury to celery in the fields of the same vicinity. It is probable, therefore, that the occurrence of the disease in the field there was correlated with low temperature.

Other investigators have noted the fact that certain plants break down following exposure to low temperatures. Harvey (13) has shown that the leaves of tomato plants become spotted with brown spots if long exposed to a temperature of 5° C. It has been demonstrated by

Molisch (18) that the leaves of tropical plants like *Episcia, Physodeira,* and others become severely spotted with brown spots following exposures of twenty-four hours to temperatures of 1° to 5° C.

The effect of low temperature in producing black leaf speck was tested by storing a large number of heads of cabbage in a large refrigerating room where the temperature variation was within the limits of — 1.0° to 1.5° C. Part of these heads were in an open wire basket and an equal number in a loosely covered tin box. There was an abundant supply of fresh air in this room, admitted by the frequent opening of doors. Temperature records were kept with a thermograph and showed little variation from the above figures. A second lot of heads was placed in a fruit cold storage room held at a temperature of 5° to 7° C. Part of these heads were in an open wire basket and the rest were stored in a large aluminum cooker which, when closed, was practically air-tight. The effect of the cabbage in the open basket upon dairy products nearby made it necessary to remove lot 2 from cold storage after three days. The results are given in table 8.

Table 8.—Effect of low temperature upon breakdown of cabbage in cold storage.

Lot No.	Condition of Storage	Temperature	Duration	Results
1	In covered tin box	—1° to +1° C.	17 days	Breakdown developed on all heads. Visible lesions on some heads when taken from storage.
2	In open basket	—1° to +1° C.	3 days	Slight breakdown on 2 heads.
3	In air-tight container	5° to 6° C.	17 days	Soft rot in nearly all heads. Inner leaves affected with characteristic black specks.
4	In open basket	5° to 6° C.	17 days	Sound.

While it was not expected that breakdown would occur within three days, lot 2, removed from storage after having been exposed to temperatures near 0° C. for this length of time, developed a few small black specks on the margins of the outer leaves after holding the heads at room temperature for three days. Lot No. 1, enclosed in the loosely covered tin box, was allowed to remain in storage for seventeen days. At the end of this time breakdown was apparent on the outer leaves as small black specks. After holding for three days exposed to air at room temperature, all of the heads were affected with the characteristic lesions of the black leaf speck disease. In addition to the small lesions, the midribs of some of the outer leaves were sunken at various intervals in longitudinal areas of blackened tissue which were two to four inches in extent. These lesions very much resembled those caused by *Bacterium campestre* and were at first thought to be due to infection by this organism. However, sections and cultural methods failed to demonstrate the presence of any organism within the necrotic areas. It seems unlikely, moreover, that bacteria or fungi could develop to

this extent at such low temperatures within seventeen days. These lesions were apparently a severe form of breakdown. Lots 3 and 4 were also removed from storage on the seventeenth day. All of the heads held in the open basket were normal in appearance and remained so during the usual observation period. The heads from lot No. 4 held in the aluminum container were affected with soft rot on the outer leaves and there was a pronounced krauty odor present when the container was opened. Upon removing the outer layers of leaves, black leaf speck developed on the newly uncovered leaves. This phase of the occurrence of this disease as an accompaniment of soft rot has been noted before and is discussed in Part II of this paper. Where cabbage is attacked by soft rot bacteria, the layers of sound leaves beneath those affected with the rot are often found covered with the specks characteristic of breakdown. With the outer leaves destroyed by soft rot organisms, the cells beneath are subjected to anaerobic conditions because of the consumption of the available oxygen by the bacteria at the surface area. These organisms are known to be voracious consumers of oxygen and, where soft rot is present to the extent that all the surface area is attacked, the partial or complete anaerobiosis that ensues results in some form of breakdown of the tissues deprived of oxygen.

The effect of low temperature upon the production of black leaf speck, even in the presence of an abundant supply of oxygen, is strikingly illustrated by this experiment. Slight spotting of the leaves occurred after the short exposure of only three days to an average temperature of 0° C. and severe breakdown followed a storage period under the same conditions for seventeen days. An exposure of three days at 0° C. is usually ineffective in producing black leaf speck. The evidence at hand seems to show that black leaf speck occurs at low temperatures, near 0° C., despite the presence of an abundant supply of oxygen, and that it also is produced at higher temperatures when for any reason a constant supply of oxygen is not available. The temperature range tested in these experiments include those to which plants in storage and transportation are ordinarily subjected.

Whenever temperature or aeration conditions in storage or transportation are such as to restrict or make unavailable a constant supply of oxygen black leaf speck may be expected to result if these conditions are of sufficient duration.

II

REDHEART OF CABBAGE AND HEAD LETTUCE

Introduction

During the course of the investigations reported in the first part of this paper, it was found that, under certain conditions of poor ventilation and also low temperatures, the heart leaves of cabbage become affected with a trouble tentatively designated as redheart. Heads affected with soft rot were also subject to the same disease.

The solid-headed types of lettuce are very commonly affected with this trouble and it is in this crop that the disease assumes considerable importance. It has been noted for several years in the "Wonderful" variety of lettuce from the western states sold under the trade name of "Iceberg." Redheart is most frequently seen in shipments on local markets and which have been held for some time under refrigeration or under conditions which are unfavorable for thorough ventilation. It is also an accompaniment of soft rot; and, almost invariably, heads that are badly attacked by soft rot show this type of breakdown in the heart leaves.

The disease had been observed prior to the initiation of the investigations on black leaf speck of crucifers, and the reaction of cabbage to ventilation and refrigeration experiments suggested the probable nature of the disease in lettuce. Experimental work was begun while the black leaf speck investigations were in progress and because of the distinct symptoms presented by this particular type of breakdown it has seemed advisable to present the results separately.

Economic Importance

No figures are available as to the losses caused by this disease. As a transportation disease on lettuce it seldom attains a rank of major importance. It is only after the crates of lettuce have been sent out in lot shipments and are placed on the market by the retailer that the trouble is manifested. The disease has not been found in the original car lot shipments when examined at destination. However, entire crates have been seen in wholesale houses and the markets which were almost worthless because of the presence of redheart. The method of shipping the solid-headed varieties of lettuce is very conducive to the development of soft rot and it is following this disease that redheart is most serious. Usually the crates are repacked and filled with ice, resulting in a great deal of bruising, with the subsequent development of soft rot. Before such heads are offered for sale by the retailer the rotted outer leaves are trimmed away and the heads appear to be entirely sound. If, however, they are cut open the heart leaves often will be found to be reddened and the head worthless. The general practice of holding stocks of lettuce in refrigerators retards the development of soft rot but is apparently favorable to the occurrence of redheart. In cars long delayed in transit or held for an unusual length of time before unloading, this trouble may cause considerable damage to head lettuce and will not be apparent for sometime after unloading. The disease is most conspicuous during the late winter and early spring months. Head lettuce bought after February, in a great many cases, is affected with redheart. The occurence of the disease at this time of the year is probably correlated with a more extensive development of soft rot. The disease in cabbage occasionally causes serious damage. It was reported by the perishable freight inspection service of one of the large railroads as the cause of considerable loss in cabbage from the storage houses of New York state in 1920-21. Carload lots of cabbage in transit after January, 1921, were found to be commonly affected with redheart (pl. 6, C). This cabbage had been held in the commercial storage houses in the usual way and apparently the disease was due to the conditions prevalent there dur-

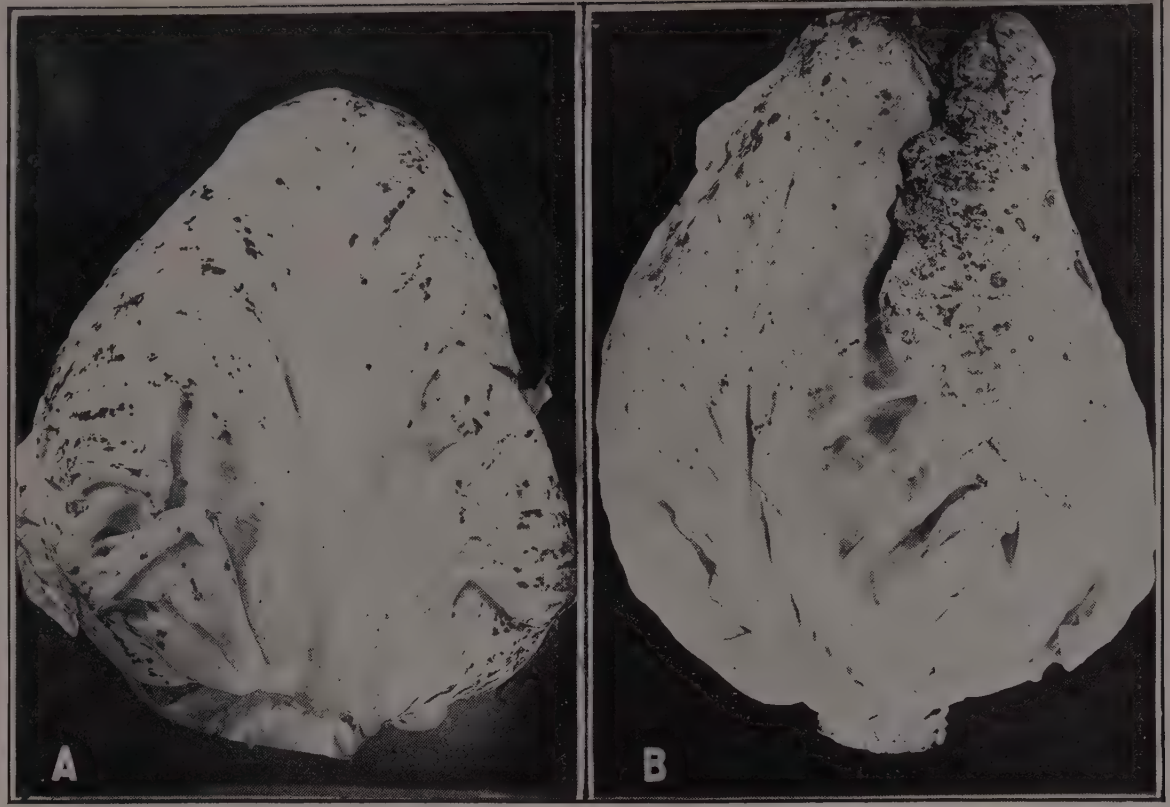

PLATE I

A. Black leaf speck on California cabbage. The outer leaves have been removed to show the extent to which the deeper layers of leaves may be affected.

B. California cabbage affected with black leaf speck. Collected in March, 1919.

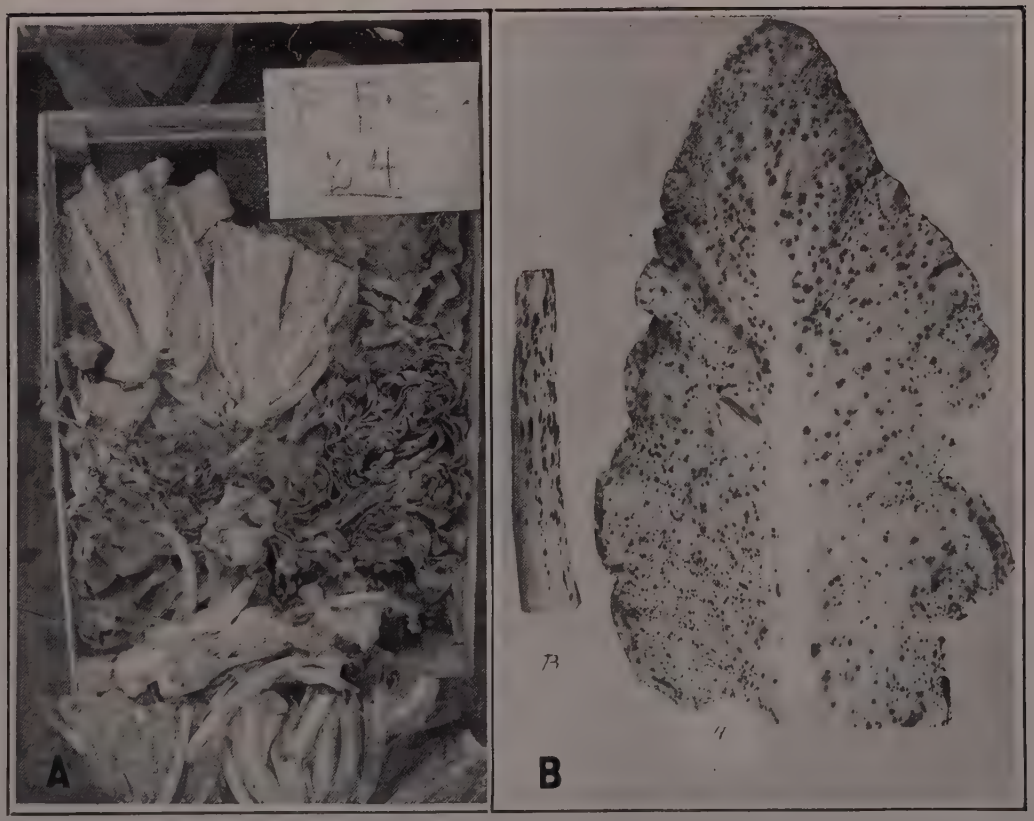

PLATE II

A. Black leaf speck on Oregon cauliflower. Collected from Pacific Fruit Express refrigerator car 24 in Detroit, March, 1919.
B. Photograph of an individual leaf and petiole from a head of cauliflower shown in A.

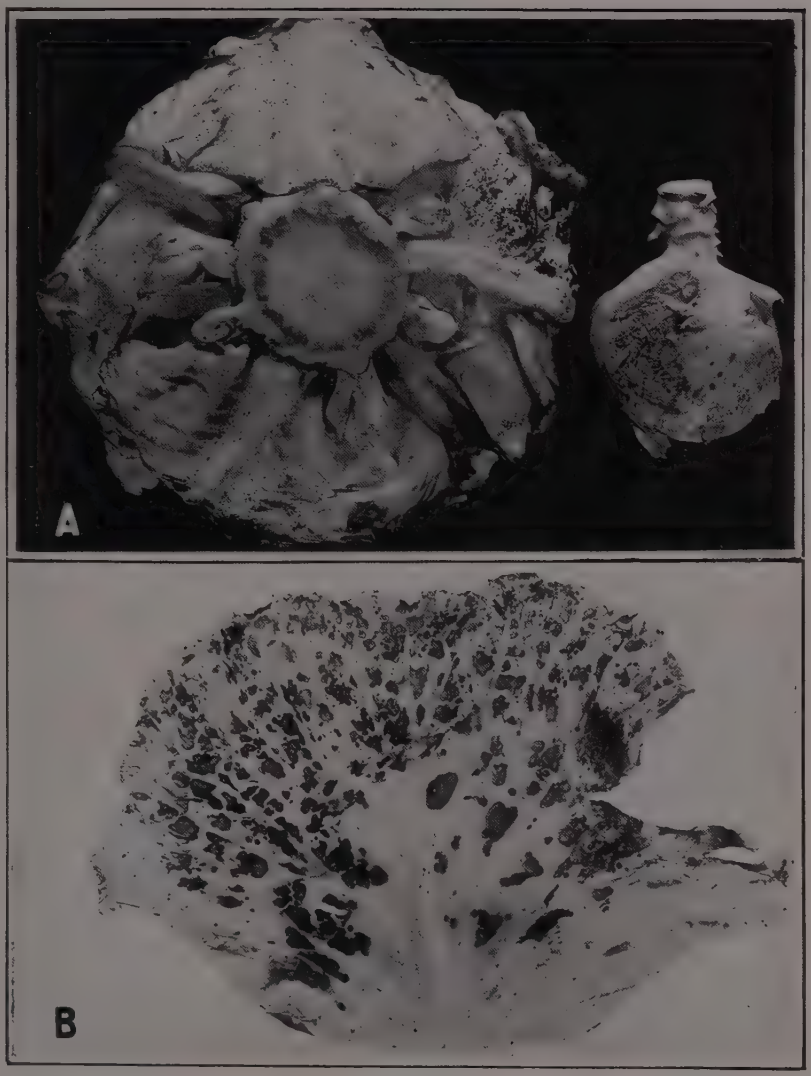

PLATE III

A. Black leaf speck on Michigan cabbage pitted over winter out-of-doors. Photographed in April, 1920. The small head grew from an axillary bud, several smaller ones of which are shown on the mother head.

B. Black leaf speck on a leaf of California cabbage. The large lesions are due to the confluence of smaller spots of the black leaf speck disease.

PLATE IV

Black leaf speck on Chinese cabbage. The disease developed in the field after heavy frosts in the early fall.

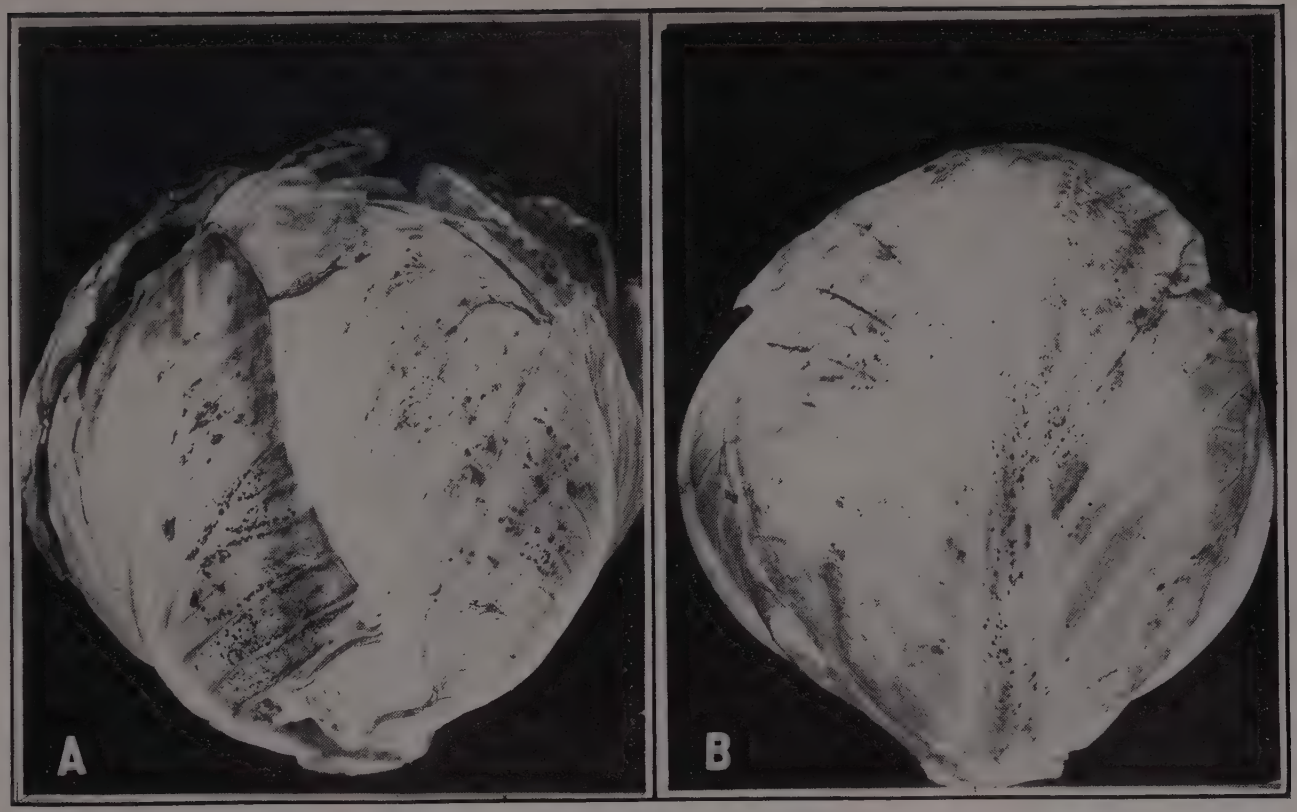

PLATE V

A-B Black leaf speck produced on cabbage by storing the heads for twelve days in an air-tight container at a temperature of 10° to 12° C. The characteristic black specks developed in 24-48 hours after removal of the heads from storage.

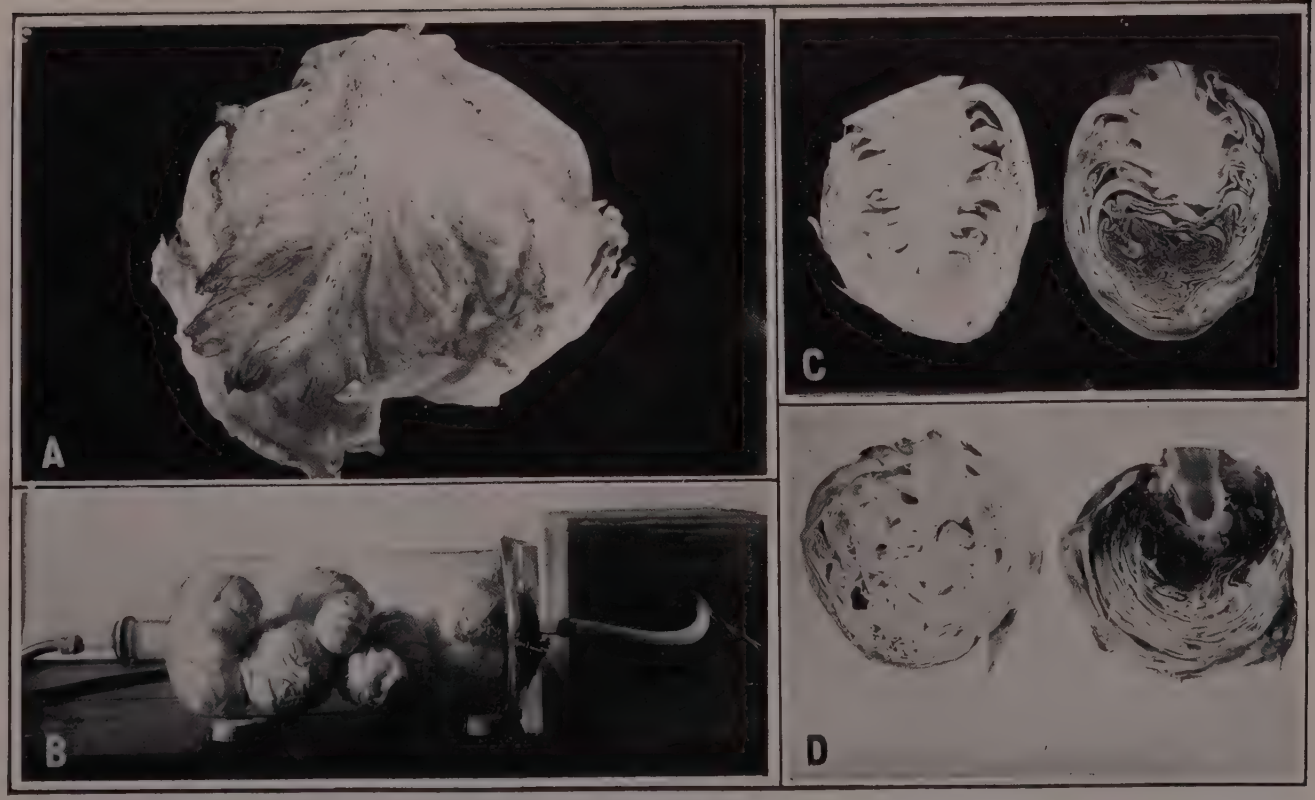

PLATE VI

A. Brown leaf speck on "Iceberg" lettuce as an accompanying symptom of redheart shown in D.

B. Apparatus used for constantly circulating air around heads of cabbage without affecting renewal.

C. Redheart in New York cabbage. Detected while in transit in January, 1921. A sound half-head is shown for comparison (left).

D. Redheart of "Iceberg" lettuce produced by storing the heads in nitrogen for four days at room temperature. The gas was changed twice daily. A sound head from the check is shown at left.

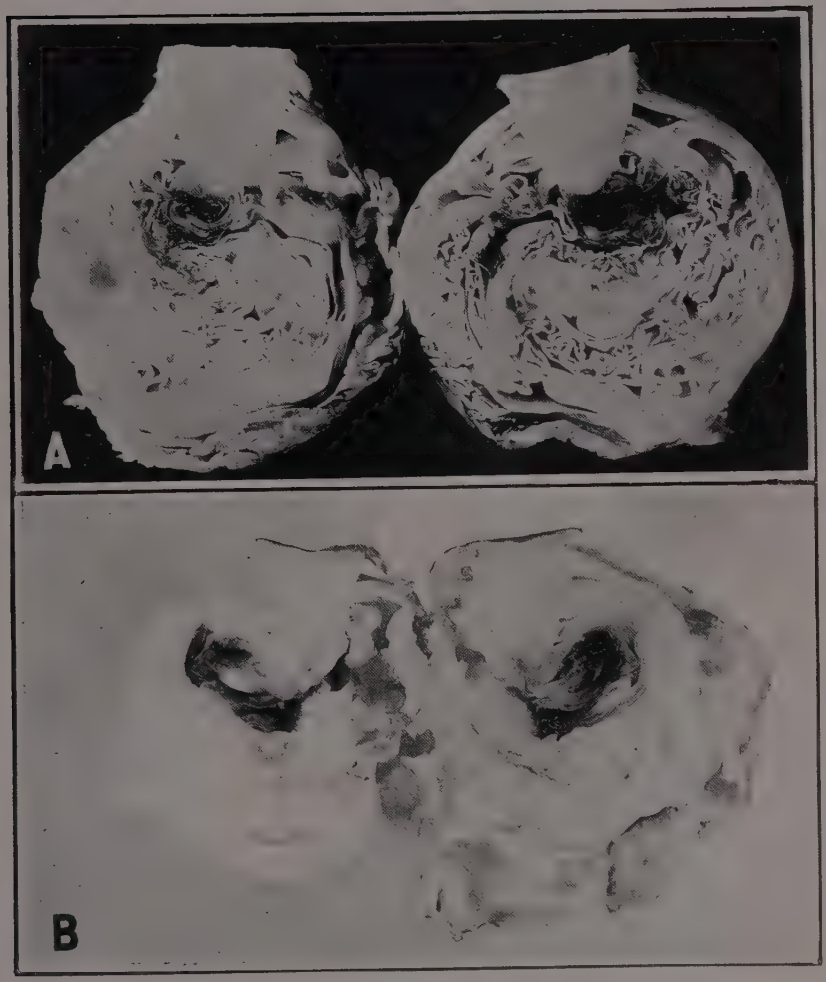

PLATE VII

A. Redheart of "Iceberg" lettuce, showing the development of the disease three hours after removal of the heads from storage in nitrogen for four days.

B. Redheart of "Iceberg" lettuce following an attack of slimy soft rot on the outer leaves.

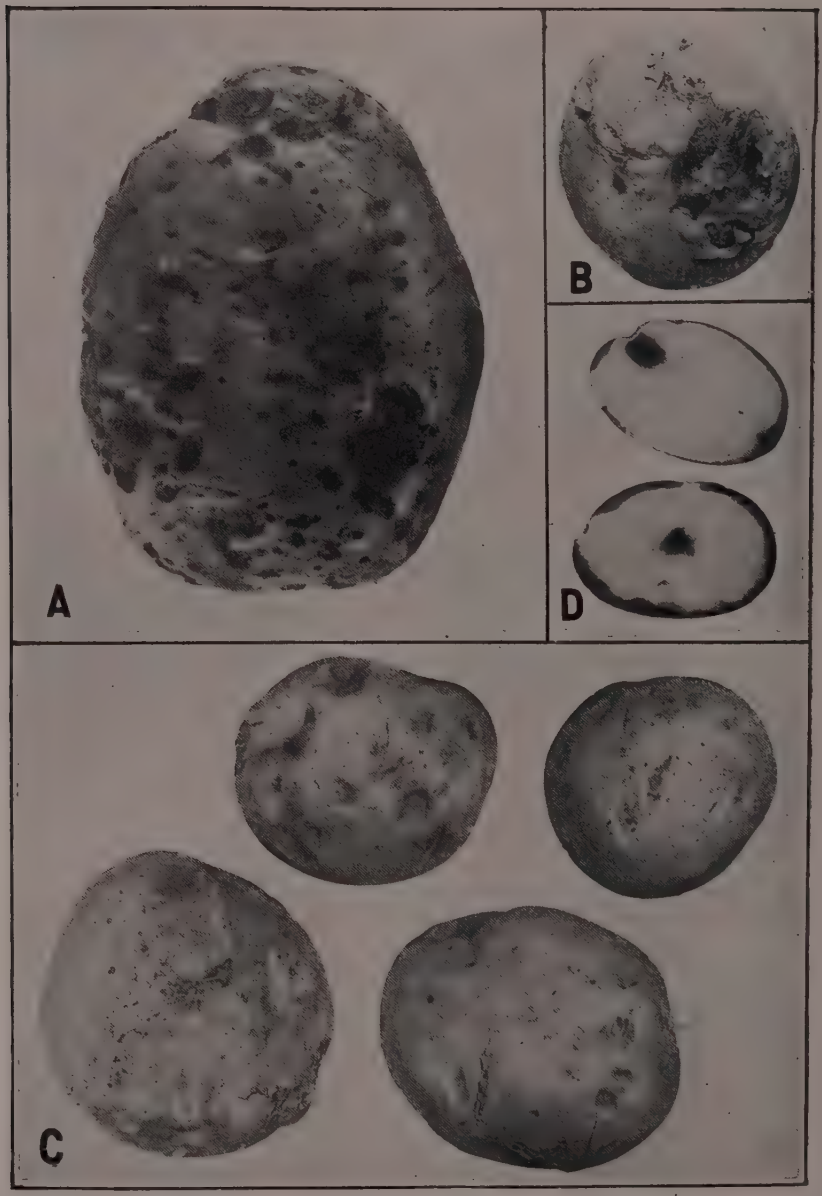

PLATE VIII

A. Surface breakdown of potato tuber. Tuber collected from car lot shipment of Michgan potatoes to Chicago in 1921.

B. Surface breakdown occurring on Michigan potatoes in the field in the fall of 1924. The tuber shows typical pitted areas which caused serious reduction in the value of the crop in several counties.

C. Surface breakdown produced on potato tubers by storage for five days in nitrogen at room temperature.

D. Breakdown of cortical tissues resulting in surface pitting and the production of slight blackheart in tubers stored in nitrogen for five days at room temperature.

ing the period of storage. The disease has not been observed in commercial lots of cabbage in Michigan but it is probably present in greater or lesser amounts each year. Since the conditions which are favorable for the production of black leaf speck have been shown also to produce redheart, it seems logical that where the former disease occurs in its more serious form that redheart will also be present. Where the storage houses are systematically aerated and the temperature is held a few degrees above 0° C., the disease is probably of little importance. Cabbage shipped in crates is unlikely to be affected unless excessive delay occurs or soft rot develops.

Name of the Disease

This disease has apparently not been reported in the literature on cabbage or lettuce diseases. The name redheart is suggested since it describes the chief symptom of this type of breakdown. There is some variation in the color of the diseased portions of the heads of cabbage and lettuce; and, while the name redheart more clearly describes the color of the cabbage leaves, it is not inappropriate for lettuce.

Description of the Disease

This type of breakdown is distinguished by the characteristic reddish color of the heart leaves both of cabbage and lettuce. In cabbage, these leaves are a typical red color; while, in head lettuce, they are a deep chestnut brown. Under experimental conditions, these colors have been observed to develop gradually, the affected leaves of lettuce passing successively through the color changes of walnut brown, neutral red, Indian purple, to chestnut brown. In cabbage, the leaves at first appear slightly infiltrated then a gradual change occurs from a light pink to a deep red color. In plate 6, C, is shown the half of each of two heads of cabbage, one of which is sound and the other is affected with redheart.

The outer leaves may or may not be affected with black leaf speck when redheart is present. Usually when the former disease is abundant on the outer leaves redheart is also found in various stages of development which may range from only a small discolored area to the involvement of the entire central portion of the head.

Occasionally, the outer leaves of head lettuce affected with redheart develop numerous pits on the midribs and veins and sometimes in the parenchyma between the veins. There pits are similar to the lesions of black leaf speck on cabbage but are a chestnut brown color like the heart leaves. These lesions are small and usually somewhat elongated, with the longer axis parallel to the midrib. In plate 6, A, is shown this tye of breakdown on a head of "Iceberg" lettuce. This phase of breakdown usually escapes notice because it most commonly occurs on the outer leaves and these leaves are removed before the lettuce is placed on the retail market. When it does occur, the presence of these lesions is a good index of the condition of the heart leaves, for redheart is also usually present.

Experimental Work

Since the previous work with cabbage had indicated the importance of securing sound heads for experimental work, all lettuce used was carefully selected and held at room temperature for observation for three days before storing. The variety, "Wonderful," commonly sold as "Iceberg," was used in all these experiments. In each case, a number of heads were cut open to determine the soundness of the heart leaves and a large number of heads were used for checks. The first experiment consisted of storing sound heads in nitrogen and in air and subjecting them to aerations with these same gases. A third lot was inoculated with five strains of soft rot bacteria (fluorescent type, isolated by L. R. Tisdale from rotting lettuce from various locations) and held in loosely covered tin boxes lined with moist filter paper. About half a dozen heads were inoculated with each strain of the soft rot organism. Lots 1 and 2 were each stored in large glass jars and aerated twice daily for thirty minutes with nitrogen and air respectively. This was continued for four days while lot 3, inoculated with the bacteria, was held until the soft rot was well developed, twelve days. Uninoculated checks were stored in a similar way. The results are given in table 9.

Table 9.—Effect of storage conditions upon the development of redheart in head lettuce; tests at room temperature.

Lot	Storage Conditions	Duration of Storage	Results
1	In large glass jar connected to tank of nitrogen. Nitrogen changed twice daily	4 days	When first cut open all heart leaves normal color. Change successively to walnut brown, neutral red, Indian purple, chestnut brown. Sunken pits on outer leaves, neutral red color.
2	Same as above but air used in place of nitrogen	4 days	Heads all normal in appearance. No redheart developed in 5 days. No pits on outer leaves.
3	6 heads in each of 5 tin boxes. Inoculated with 5 strains soft rot bacteria.	12 days	All outer leaves rotted with slimy soft rot. Hearts of all heads typically affected with redheart.
4	Same as above but sterile water used for inoculation	12 days	Sound. No redheart in any heads.

Lots 1 and 2 were removed from the jars at the end of four days' storage and immediately cut open to determine the condition of the heart leaves. The heart leaves of all heads from lot 1, when first examined, appeared normal except for a slight infiltration which gave a dull appearance to the hearts of the heads. In three minutes, this had become a walnut brown color and passed through the following color changes; in fifteen minutes, neutral red; two hours, Indian purple; three hours, chestnut brown; after which no further change in color occurred. Ridgway color standards were used for comparison. In plate 7, A, is shown one of these heads 3 hours after cutting open.

All the heads aerated with air were sound and developed no condition resembling redheart. All the heads inoculated with each strain of soft rot bacteria developed a typical case of slimy soft rot; the outer leaves becoming soft, slimy and largely disintegrated. Every head in these five separate lots was affected with a typical case of redheart; the disease being fully developed when the heads were first cut open (plate 6, D). The uninoculated heads were sound at the end of the twelve days storage period and were free from redheart or any other symptoms of breakdown.

This experiment indicated that breakdown in the form of a reddening of the heart leaves and the development of sunken lesions of the same color on the outer leaves could be satisfactorily reproduced under controlled conditions very similar to those to which lettuce is exposed in transportation, storage, and the open market. Poor ventilation, resulting in a progressive decrease in the available oxygen, is undoubtedly one of the causes of breakdown of this type and the universal presence of soft rot on head lettuce sold on the markets is probably one of the most common causes of redheart.

The production of redheart and black leaf speck in cabbage at low temperatures suggested the possibility that the same factor might be effective in producing the disease in lettuce. A crate of sound "Iceberg" lettuce was obtained and divided into two lots. The heads of lot No. 1 were placed in two large loosely covered tin boxes and stored in a cold storage room where the temperature ranged from — 1.0° to 1.0° C. The heads of lot No. 2 were placed in wire baskets in a refrigerator at a temperature of 8° to 10° C. Examinations were made of each of these lots at intervals of several days. At the end of three weeks, one box was removed from cold storage and one from the refrigerator. The remaining heads of lot No. 1 were left in storage for an additional three weeks, while those in the refrigerator were removed after a total storage period of four weeks. The behavior of these various lots of lettuce is shown in table 10.

Table 10.—Effect of low temperature upon the development of redheart in Iceberg lettuce.

Lot No.	Storage Conditions	Temperature	Duration Storage	Results
1	Loosely covered tin boxes in cold storage room	—1.0° to 1.0° C	3 weeks	Sound. No redheart developed in 3 days after removal from storage.
2	Loosely covered tin boxes in cold storage room	—1.0° to 1.0° C	6 weeks	Redheart in 30% of the heads after 24 hours at room temperature. Sunken red lesions on the outer leaves.
3	Open wire baskets in ordinary refrigerator	8°–10° C	3 weeks	Redheart in 50% of the heads.
4	Open wire baskets in ordinary refrigerator	8°–10° C	4 weeks	Soft rot and redheart in all heads,

Examination of the table will show that no redheart was produced in the lettuce stored for three weeks at a temperature of —1.0° to 1.0° C. but that a similar period of exposure to a temperature of 8° to 10° C. resulted in the production of the disease in 50 per cent of the heads. This is partially explained by the fact that no soft rot developed on the heads at the lower temperature while the heads developing redheart were also affected to some extent with soft rot. However, some of the heads that were affected with breakdown of the heart leaves did not develop sufficient rot to account for its occurrence. One week later all of the heads at the higher temperature were attacked by slimy soft rot and redheart was present in every one of these (pl. 7, B). After six weeks of storage at the lower temperature, 30 per cent of the remaining heads in cold storage had developed breakdown which was evident within 24 hours after removal from storage. In addition, the red sunken specks were abundant on some of the outer leaves. These lesions were similar to those of black leaf speck on crucifers except for their color. The results of this experiment, while differing somewhat from those obtained with cabbage, are in agreement as to the production of the disease by exposure to low temperature even in the presence of an abundant supply of oxygen.

Typical redheart of the type that occurs in lettuce and cabbage in storage, and which frequently develops after transcontinental shipment in refrigerator cars, has been reproduced by the conditions of the foregoing experiments, namely: restricted aeration or limited oxygen supply; secondary effect of soft rot, which effectively inhibits free gas exchange; and storage at low temperatures similar to those maintained in cold storage and in certain areas within refrigerator cars. In some respects, especially reaction to temperatures near 0° C., lettuce appears more tolerant to unfavorable conditions than cabbage; but in general the response of these two vegetables to similar conditions of aeration and temperature is fairly uniform. The expression of this reaction apparently differs somewhat in the parts of the head most susceptible; in cabbage, the outer leaves; in lettuce, the heart leaves. That black leaf speck and redheart are expressions of a reaction to similar unfavorable conditions is shown by the fact that the reddening of the heart leaves of both cabbage and lettuce is a mutual response to the same physical conditions; and that the breakdown, in the form of black specks, of certain areas of the outer leaves of cabbage can often be produced in lettuce, in the form of reddish specks of the same type, by a prolongation of the exposure to the unfavorable storage conditions which cause redheart. The occurrence of leaf speck and redheart in either a head of cabbage or lettuce may be interpreted as a compound reaction of these vegetables to similar unfavorable environmental conditions.

III

SURFACE BREAKDOWN OR "BUTTON ROT" OF POTATO TUBERS

Introduction

The peculiar surface pitting of potatoes that occurs in storage and transportation in late winter has been under observation for several years. This disease has been known for sometime by the trade as "Button Rot." As an accompaniment of blackheart, this type of surface breakdown has undoubtedly been generally overlooked, while its occurrence in the absence of blackheart has wrongly been considered as due to the attack of some species of *Fusarium*. Apparently, no direct investigational work has been done to determine the cause of this disease but observations on the incidental occurrence of the trouble have been made by Stewart and Mix (27) and Bennett and Bartholomew (4) in their investigations of blackheart. The importance of this disease as a storage trouble has been emphasized by the numerous inquiries received concerning its nature and methods of control.

Importance

Attention has been directed to this type of breakdown because of its increasing prevalence during the past few years in storage houses, pits, and cellars. The losses sustained by the growers who hold their potatoes for late winter or spring shipment has raised this disease from the rank of a minor blemish to a place of major importance in the storage diseases of this crop. In some years, it is the most important storage disease of potatoes.

Actual losses are difficult to determine due to the fact that slightly affected tubers are salable but at a reduced price. Where blackheart is not a complicating factor the disease merely is an unsightly blemish, but in severe cases where secondary rots accompany the breakdown the affected tubers are worthless. Kotila (14) has made some first hand observations on the prevalence and losses caused by this disease in the storage houses of Michigan. The disease was particularly severe in the late winter of 1923. Losses of from 25 to 30 per cent were not uncommon in some of the larger storage houses. While these figures cannot be taken as an indication of the average importance of the disease as a storage trouble they do represent the possibility of deterioration that may arise as the result of favorable conditions for the occurrence of this trouble.

Where the disease occurs in potatoes under transportation, the condition very often has had its inception in the storage house. It may arise, however, as the result of unfavorable conditions within the car and in many cases is complicated by various secondary rots and internal breakdown as blackheart. The tubers may be exposed to the conditions necessary for the production of breakdown while in

storage and show no symptoms until after removal. This makes a particularly difficult problem for inspectors who are confronted with the necessity of determining responsibility. In such cases, storage house inspection is the only method of solving the difficulty and necessitates careful investigation.

As a field disease, this type of breakdown has been seldom observed. In the fall of 1924, Michigan potatoes in several counties were affected. Losses in some cases were serious. The disease was apparent at digging time, following an extended period of hot and very dry weather. The soil was very dry and the tubers when dug were badly blemished and in most cases unsalable (pl. 8, B). The crops grown on the heavier soils were apparently more seriously affected. The condition was first diagnosed as late blight rot but no organisms could be demonstrated in the affected tubers; and, in addition, late blight was known to be absent from the fields in which the disease occurred. Tubers from certified fields were included among those showing breakdown of this type.

Symptoms

The disease is characterized by a shallow surface pitting of the tubers, brought about by the death of certain areas of the cortical and adjacent cells and the subsequent desiccation of the dead cells. The appearance of diseased tubers is well illustrated in plate 8, A. All gradations in the severity of the disease in its effect upon the tubers may often be observed in the same lot of potatoes. The pits may be small and very numerous and only slightly depressed below the surrounding healthy tissues, but where large areas are involved the individual pits are usually fewer in number and extend deeper into the flesh. In the more severe forms of the disease, this extension of the pitted area is often correlated with the secondary attacks of fungi, usually *Fusaria*. In the initial stages of the disease, the pits are usually small, the surface is hard, and the margins are fairly regular in outline with a grayish-blue color or metallic luster; and there may, or may not, be an accompanying brown discoloration of the flesh immediately beneath. In most cases of surface breakdown, blackheart is infrequently associated with the pitting but this trouble may also be found in tubers showing severe surface injury. In many respects, this surface pitting of the tuber resembles formaldehyde injury described by Stewart and Gloyer (26). It differs chiefly in the placement of the pits which bear no relation to the lenticels. The pits caused by formaldehyde injury are always lenticular in origin.

Previous Observations

Very few reports have been made of the occurrence of this disease in the literature of potato diseases. Stewart and Mix (27) noted the appearance on tubers, which were stored in tightly closed jars for ten to twelve days at temperatures near 70° F. of small, circular, dead depressed areas from two to five mm. in diameter and resembling the spots produced by fumigation with formaldehyde. They report the tubers severely injured by the occurrence of these spots. This trouble was probably identical with, or related to, the type of breakdown under consideration in this paper. Link and Gardner (16) report this

type of pitting on market potatoes and suggest that it is the result of freezing injury. Coons and Kotila (7) report the general occurrence of the disease in Michigan storage houses and in potatoes stored in pits. The disease was particularly severe in the winter of 1922-23. Recently Bennett and Bartholomew (4) report the occurrence of surface injury as an accompaniment of blackheart produced under low temperature conditions. They do not describe the kind of injury produced and it may or may not have been of the pitting type.

Experimental Work

Following the successful production of black leaf speck in cruciferous plants by storing them under conditions of restricted aeration and also the production of redheart in cabbage and lettuce under similar conditions, the pitting of potato tubers in storage and transportation was suspected of being of like origin. In some of the experiments with cabbage, lettuce, and fruits, a few potatoes were enclosed in the storage jars and the effect of the various storage conditions noted. The first experiment, in which potatoes were used exclusively, was set up in February 1921. Sound, clean tubers of the Rural variety were used and they were stored as follows: lot 1 in a large glass jar sealed tightly, with connections arranged for replacing air with nitrogen gas; lot 2, the same as lot 1 but arranged for aeration with air; lot 3 in an open basket. In table 11, are shown the results of this experiment. Lot 1, stored in nitrogen which was renewed by blowing fresh gas through the storage jar for thirty minutes daily, developed typical surface breakdown within two days after removal of the tubers from the jar. When taken from the jars, the tubers were normal in appearance and apparently entirely sound.

Table 11.—Effect of aeration with air and with nitrogen upon development of surface pitting of potatoes: tests at room temperature.

Lot	Storage	Duration	Results
1	In glass jar filled with nitrogen, renewed daily	3 days	Tubers normal in appearance when removed from jar. Surface pits developed within 48 hours at room temperature. No blackheart in any tubers.
2	In glass jar. Air blown through continuously	3 days	All sound.
3	Open basket	5 days	All sound.

No blackheart developed in any of the tubers. The tubers supplied with fresh air were sound and developed no trace of breakdown during the usual observation period. Lot 3 in the open basket was unchanged. This experiment indicated that surface pitting could be produced under conditions similar to those causing black leaf speck of crucifers and redheart of cabbage and lettuce and that apparently the exposure required to produce surface pitting was shorter than

that required to cause blackheart. Observations on the natural occurrence of surface pitting on tubers in the storage houses failed to show that blackheart was an accompanying symptom; in fact, very few cases of blackheart have been observed where breakdown was apparent as depressed areas on the surface of the tubers taken from commercial storage houses. It seemed probable that these two kinds of symptoms might result from exposure of the tubers to similar conditions and that the varying response of the tubers could be explained on the basis of the duration of exposure to the storage conditions which would produce either surface breakdown, blackheart, or both.

The next experiment was designed to produce both surface breakdown and blackheart by prolonging the storage period beyond that of the preceding experiment. In this case, the tubers were subjected to the same storage conditions as in the preceding experiment but allowed to remain in the storage jars for two additional days. An additional lot was stored in a large air-tight desiccator. The results are shown in table 12.

Table 12.—Effect of length of storage upon the production of surface breakdown and blackheart in potato tubers: tests at room temperature.

Lot	Storage	Duration	Results
1.....	Large glass jar. Nitrogen blown through 30 minutes daily.....	5 days.....	Tubers moist on surface and slightly discolored. Upon cutting tubers the cortex showed pink coloration, gradually changing to dark brown. Blackheart in nearly all tubers.
2.....	Same as 1 but air used for aeration	5 days.....	All normal. No change after holding 5 days.
4*.....	Stored in air-tight desiccator. 1 vol. of tubers to 6 volumes air.....	10 days.....	Normal in appearance when opened. All tubers developed surface breakdown as pitted areas and also blackheart.

*Air composition at end of ten days:
Oxygen—3%.
Carbon Dioxide—21%.

The tubers of lot 1 stored in nitrogen for five days were moist on the surface when removed from the storage jar and brown discolored areas were visible on the surface. Some of the tubers were cut immediately and as soon as the flesh was exposed to the air the cortex began to discolor, becoming first slightly pink and gradually changing to a dark brown color. Pink areas appeared in various regions of the flesh and typical blackheart was produced in most of the tubers of the lot. Surface pitting occurred on part of the tubers, some of which were affected with blackheart and some free from it. The tubers exposed to a continuous stream of fresh air were sound and showed no change after holding for ten days. The tubers in the open basket showed no change from the original condition except a slight withering. In plate 8, C and D show the surface pitting developed on the tubers stored in the nitrogen, also the discoloration of the cortical tissue, and the production of blackheart in the flesh. The tubers

from the desiccator showed severe surface pitting and every tuber was affected with blackheart. The gas analysis of jar 4 showed 3 per cent oxygen and 21 per cent carbon dioxide.

The conditions of storage have been modified in various ways and these experiments repeated with uniform results; namely, the production of surface pitting, blackheart, or a combination of these symptoms. In all cases, the indications have been that surface pitting may develop after exposure to conditions of storage that are not severe enough to cause blackheart. From two to five days storage in an atmosphere of nitrogen has been sufficient to produce breakdown in the form of shallow surface pits on the tubers. Potato tubers are apparently more susceptible to this form of injury in the late winter than in the fall when they withstand much more severe storage conditions. Breakdown of the tubers in storage is almost exclusively a disease occurring in the late winter and has never been noted before January. This increase in sensitiveness to decreased oxygen supply may be correlated with greater physiological activity in the tubers toward the end of the normal rest period. It seems quite probable also that pre-storage conditions of the tubers may greatly influence their behavior under experimental conditions. Bennett and Bartholomew (4) have shown that tubers stored at low temperatures until they become sweet are much more subject to injury by high temperatures than non-sweet tubers and this is probably also true in their reaction to the conditions of storage that brings about surface breakdown.

In all the experiments attempted when freshly dug tubers of such varieties as Early Ohio or Bliss Triumph were used, no surface breakdown or blackheart has been produced by exposing them to the conditions which have caused pitting or blackheart in other experiments with late varieties of potatoes. Recently dug tubers break down very quickly under some storage conditions tried in the experimental work, either quickly becoming watery or affected with soft rots. No surface breakdown or blackheart has ever been noted to occur naturally on the early varieties of potatoes but there seems no reason why blackheart could not occur in such tubers since this disease has been reported in the late varieties by allowing them to lie in the field exposed to the hot sun after digging.

Gussow (12) reports an interesting case of blackheart produced in potatoes stored in a pit where the temperature varied from 32.5° to 46° F. and attributes the appearance of blackheart in the tubers to the effect of the low temperature. Moreover, he states that the pit was well ventilated. Surface breakdown due to freezing injury has been reported by Link and Gardner (16). In a recent paper Bennett and Bartholomew (4) have shown that blackheart can be produced by exposing potatoes to temperatures at or near 0° C. At 0° C., tubers sealed in air-tight jars developed blackheart after thirty-seven days, thirty of which were required for the potatoes to exhaust the free oxygen from the jars. Seven days additional exposure to an oxygen-free atmosphere was necessary to produce blackheart. At 2.5° C., which approximates commercial storage house temperatures, forty-seven days, under similar conditions, elapsed before blackheart occurred, during the last eleven days of which the tubers were exposed

Bergman (5) has demonstrated the effectiveness of the refrigerator car in preventing free exchange of air. In his determinations of the air composition in iced cars loaded with strawberries, he has shown that the CO_2 content may rise as much as 2.5 per cent within eight hours after loading the car. No data are given as to the percentage of oxygen in the air. Considering the fact that the respiratory ratio is at or near the minimum at temperatures approximating those of the refrigerator car, it is evident that the oxygen content of the air is very greatly reduced within a few hours after the cars are loaded. This condition must be more pronounced in loads of vegetables like potatoes and cabbage shipped in bulk and not ventilated. In table 2 are given the results of gas analyses of cabbage stored in air-tight jars at a temperature of 18° to 20° C. The analyses show a very rapid consumption of the oxygen during the first twenty-four hours of storage. The much slower subsequent rate is probably due to the suppressing effect of carbon dioxide upon the respiratory processes and perhaps also to the relative unavailability of the small residual quantity of atmospheric oxygen.

Low temperature, when considered alone, is probably not the cause of breakdown but the importance of low temperature as a factor in the production of breakdown diseases seems correlated with an effect upon oxidation processes and affords further indicattion of the rule of sub-oxidation in the production of these storage diseases. The detrimental influence of low temperature upon certain plants has been observed by other workers. Molisch (18) noted the severe brown spotting of the leaves of certain tropical plants following a short exposure to temperatures of 1° to 4°C. He explained this type of breakdown as the result of the accumulation of toxic substances in the cells due to incomplete oxidation.

Harvey (13) has shown that tomato plants are injured or killed at a temperature of 5° C. and that this killing is not a true freezing to death since there was no ice formation within the tissues. Black leaf speck of cabbage and redheart of cabbage and head lettuce have been produced at temperatures at or near 0° C. in the presence of an abundant supply of atmospheric oxygen. Black leaf speck and redheart occur in the commercial storage houses where the temperature is held just above freezing. Mention has been made of the occurrence of this type of leaf specking on Chinese cabbage in the field following a sudden drop in temperature to 0° C. The same phenomenon has also been observed on cauliflower. The occurrence of black leaf speck on cabbage in the field in California as reported by Link (15) may have been correlated with low temperature.

Mention has been made of the work of Bennett and Bartholomew (4) who have investigated the effect of temperature upon the respiration rate of potatoes. These workers were unable to produce blackheart at low temperatures in the presence of oxygen and not until a considerable time had elapsed after the oxygen was completely exhausted from the storage jars was blackheart produced in the tubers. Surface injury appeared in conjunction with blackheart under these conditions. No surface injury was reported in their experiments at temperatures of 20° C. and higher. In the experiments reported in this bulletin, surface injury was produced at temperatures above 20°

C., both with and without blackheart as an accompanying symptom. Surface injury occurred while a measureable amount of oxygen was still present in the storage jars. Reference has been made to the report of Gussow (12) on a case of blackheart appearing in tubers stored in a well ventilated pit but exposed to low temperature.

Potatoes in the commercial storage houses of Michigan, held at temperatures 3° to 4° C., are often seriously reduced in value late in the storage season by the surface pitting that disfigures the tubers. The relatively low temperature at which these houses are held is unquestionably not the only possible factor responsible for this trouble. Decreased oxygen supply in the bins is probably as important or more so than low temperature. The same may be true of the cabbage storage houses where black leaf speck occurs, although low temperature has been shown to cause this disease even in the presence of abundant atmospheric oxygen. Within certain limits, both factors probably operate simultaneously under storage conditions. Under transportation conditions, decreased oxygen supply and low temperature are concerned and the influence of each will largely be determined by the degree of exclusion of fresh air, the temperature, and the period of exposure as determined by the length of the haul.

At a temperature of 2° to 4° C., the respiratory ratio is at a minimum as shown in the results of Puriewitsch given by Palladin (21). At these temperatures, oxygen absorption proceeds much faster than the elimination of carbon dioxide and, therefore, oxidation is not complete in the cells. The effect of low temperature must then be to slow up at some point the oxidation processes in the cell although the quantity of atmospheric oxygen in the storage air may continue to be depleted at a rapid rate. The process of oxidation of compounds in the cell may be so affected that toxic substances are formed which remain sufficiently long in the cell to cause injury to, or death of the protoplast.

Air movement without renewal has not been effective in preventing these breakdown diseases. The rapidity with which black leaf speck was produced at low temperatures indicates that change of air may not be effective in preventing breakdown at temperatures near freezing. The negative results obtained by exposing sound heads of cabbage to the gaseous compounds produced by other heads stored in closed chambers seem further to indicate that intracellular compounds and not volatile ester-like compounds are concerned in the production of the disease. In this respect, these diseases differ from apple scald.

The data obtained in the experimental work and observations on the occurrence of the various forms of these diseases afford a satisfactory explanation for the variety of symptoms shown under different storage conditions. It has been observed that surface pitting of potato tubers occurs in commercial storage houses in the absence of blackheart. The same thing is true of black leaf speck which is not necessarily an accompaniment of redheart. It was shown experimentally that, under the most unfavorable conditions of storage, redheart of cabbage might be produced. At a temperature of 37° C., redheart is produced very readily and undoubtedly is comparable to blackheart of potato. Redheart may also be produced at a temperature of 20° C. if the cabbage is stored long enough to deplete the oxygen. Speck-

adoption of similar methods in the cabbage storage houses so that ventilation is secured in the piles of heads will do much to prevent the development of black leaf speck and redheart. In addition, the temperature of the storage houses should be carefully regulated so that a mean of 3° to 5° C. is maintained in conjunction with good ventilation. This is especially important immediately after storage since it is probable that there may be some compensation for unfavorable conditions later in the season in thorough ventilation and well regulated temperature for a few weeks immediately following storage.

Potatoes appear most susceptible to breakdown troubles in late winter. This may be due to a greater physiological activity of the tubers at this time or to the cumulative effects of unfavorable conditions during the long period of storage. Thorough ventilation should be supplied to prevent any possible predisposition to these troubles.

In the shipment of potatoes and cabbage in bulk, some provision should be made for air circulation through the stowed vegetables themselves. False floors should be generally used and during cold weather periods when the temperature outside is too low to allow the ventilators being opened constantly during the journey they should be opened for a short time, if possible, at intervals. This is most important in the case of cabbage and cauliflower shipments from the Pacific coast and Florida.

The prevention of redheart in head lettuce is, in large part, a problem in the control of soft rot. Lettuce should not be held long in storage and the trimming away of the outer leaves attacked by soft rot organisms should be done frequently in case of delayed sale to prevent soft rot from developing and causing suffocation of the heart leaves of the head.

Summary

This bulletin presents the results of the investigation of certain nonparasitic diseases affecting crucifers, lettuce, and potatoes in storage and transportation. These diseases include black leaf speck of crucifers, redheart of lettuce and cabbage, and surface pitting of potato tubers.

All these diseases are symptoms of breakdowns that occur under present conditions of storage and transportation and are caused primarily by an inadequate supply of oxygen or by temperatures which prevent the utilization of the oxygen present.

These breakdown diseases have been produced in the laboratory under various conditions of temperature and air composition and both of these factors are important in causation.

Air movement without renewal has not been effective in preventing breakdown and at low temperatures air composition appears to be less important than low temperature as a cause of these diseases.

Surface breakdown of potato tubers occurs in the absence of blackheart and may be produced by exposure to conditions less severe than is required to produce blackheart.

It is suggested that the ultimate cause of these diseases is the liberation or accumulation in certain cells of some toxic fragment resulting from the mixing of hydrolytic enzyme and glucoside. The conditions necessary for this reaction are brought about in storage and transpor-

tation by prolonged exposure to low temperature or an inadequate oxygen supply.

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